

## Scaling resistance of deposited metal by flux-cored wire 30N8Kh6M3STYu

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**Abstract.** The scaling resistance of a coating deposited by a flux-cored wire 30N8X6M3STYu subjected to surface oxidation at a temperature of 900 °C was studied. It was established that the main increase in the mass of scale for a given metal occurs in the first hours, and later this dependence is almost straightforward. The average weight gain of the metal scale of such a coating at 900 °C is 0.002 kg/(m<sup>2</sup>·h), which is 16.5 times less than that of 30Kh2V8F steel. An X-ray analysis of a metal of the composition 30N8X6M3STYu showed that the scale consists not only of the oxide phase, but also of the remnants of non-oxidized grains of solid solution, nitrides and carbides. It was found that the basis of scale, along with hematite Fe<sub>2</sub>O<sub>3</sub>, magnetite Fe<sub>3</sub>O<sub>4</sub>, are various compounds of the main alloying elements such as Cr<sub>2</sub>FeO<sub>4</sub>, Fe<sub>2</sub>NiO<sub>4</sub> and Fe<sub>3</sub>N, which have good protective properties. The results show that the coating of steel 30N8Kh6M3STYu can be used for applying on the surface of parts operating at high temperatures.

### 1. Introduction

The efficiency of metallurgical production is largely determined by the operability of the hot metal deformation tool. In its turn, the operational reliability of the tool is directly dependent not only on its wear resistance, but also on the intensity of the scale formation process [1]. In addition, when heated, the metal surface interacts with oxygen, which leads to the formation of scale [2]. As a result, the chemical composition of the surface layer of the metal changes and its operational properties decrease [3]. Scale has abrasive properties due to its significant hardness, which is maintained at high temperatures of hot processing. Therefore, the presence of plentiful scale in the contact zone enhances tool wear. Therefore, the problem of increasing the operability of a tool that works not only in conditions of abrasive wear, but also at high temperatures is extremely important.

It is possible to increase the service life of the working surfaces of the tool by surfacing with new types of wear-resistant steels [4–6]. From this point of view, the processes of applying wear-resistant coatings on economically alloyed martensitic steels deposited by flux-cored wire to the working surfaces are widely used [6, 7]. In this regard, precipitation hardening nickel-chrome steels alloyed by molybdenum, silicon, titanium, and aluminum are promising [8, 9].

Previous studies of such steel 30N8Kh6M3STYu (alloying systems 0.03%C–8.0%Ni–6.0%Cr–3.0%Mo–1.0%Si–0.55%Ti–0.30%Al) found that it has a significant hardening effect as a result of aging and can be used for wear-resistant surfacing [10]. However, the features of the operation of such steel at high temperatures have not been studied.



In this regard, the features of scale formation and changes in the structure and phase composition of 30N8Kh6M3STYu steel as a result of exposure to high temperatures in the air were studied.

## 2. Objects and methods of research

The object of research was cast steel coating deposited by flux-cored wire based on steel 30N8Kh6M3STYu. To ensure the necessary carbon content in steel, high-carbon FeCr was introduced into the composition of the flux-cored wire. The calculated composition of the experimental flux-cored wire is shown in table 1.

**Table 1.** The calculated composition of the experimental flux-cored wire, %.

Ni	FeCr	Mo	FeSi	FeTi	FeAl	Na <sub>2</sub> SiF <sub>6</sub>	Fe	Fe-type
8.5	8	3.5	2.6	5.2	1.8	0.3	16.5	rest

For comparison, the metal obtained by surfacing with chromium-tungsten steel 30Kh2V8F, widely used for the manufacture of a hot metal deformation technological tool, was investigated.

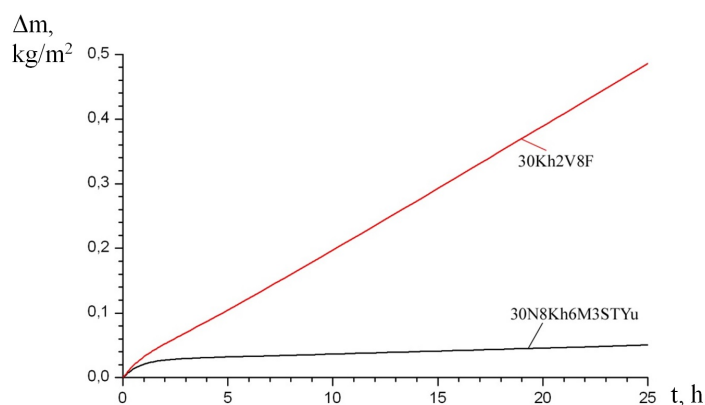
Tests of the experimental composition of the coating metal for scale resistance (heat resistance) were carried out in a calm air atmosphere according to Russian state standard GOST 6130–71 [11]. An increase in the mass of samples at a temperature of 900 °C during a test period of 25 hours was chosen as a characteristic of scale resistance.

Metallographic studies of oxidized samples were performed using a JEOL JCM-5700 scanning electron microscope with a JED-2300 energy dispersive spectrometer.

X-ray phase analysis of oxidation products was carried out on a Shimadzu XRD-7000 multifunctional X-ray diffractometer. To process and analyze diffraction spectra, the Match! Software package version 3.8.1.151 was used.

## 3. Results of the experiments and discussion

The change in the mass gain of a metal deposited by a flux-cored wire of composition 30N8Kh6M3STYu and metal deposited by a wire 30Kh2V8F depending on the exposure time in an oxidizing atmosphere is shown in Figure 1.



**Figure 1.** Change in the increase in mass  $\Delta m$  of the metal 30N8Kh6M3STYu and 30Kh2V8F from the exposure time at 900 °C.

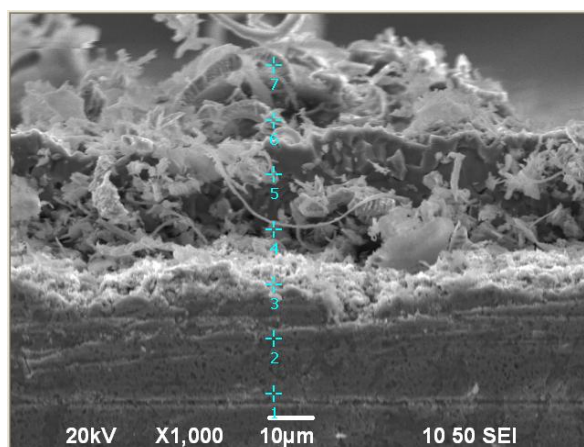
The graph shows the jump in the increase in the mass of scale on the surface of the metal 30N8Kh6M3STYu occurs during the first hour. Over the next four hours, no increase in the mass of scale was observed. After five hours of testing, the growth rate of scale increases, but to a much lesser extent than in the first hour of testing, and in the future this dependence is almost straightforward. So, if in 1 hour of testing the increase in the mass of scale was about 0.0295 kg/m<sup>2</sup>, then in 5 hours it was only 0.0216 kg/m<sup>2</sup>, and after 25 hours only 0.0506 kg/m<sup>2</sup>. Moreover, the thickness of the scale after 1 hour of testing at 900 °C is only 9.37–18.25 microns, and after 5 hours – 27.45–40.07 microns. On the

surface of a 30N8Kh6M3STYu metal sample that passed 25 hours of testing, a uniform thin layer of light gray dense scale formed, the thickness of which remained virtually unchanged and amounted to 35.74–55.28 microns.

The scale formation indices of steel 30Kh2V8F are significantly worse than metal 30N8Kh6M3STYu. So for 1 hour of testing, the increase in the mass of scale was about 0.0397 kg/m<sup>2</sup>, for 5 hours it was already 0.0986 kg/m<sup>2</sup>, and after 25 hours 0.4858 kg/m<sup>2</sup>. The thickness of the scale after 1 hour of testing at 900 °C is 44.17–52.29 microns, and after 5 hours – 70.07–81.17 microns. On the surface of a sample of 30Kh2V8F steel of the past 25 hours, the thickness of the oxide layer increased significantly and amounted to 491.67–519.37 microns.

To identify the causes of increased scale resistance of the metal deposited by flux-cored wire 30N8Kh6M3STYu, the structure and phase composition of the deposited metal and scale were studied.

The microstructure of the thin section of the lateral surface of the metal 30N8Kh6M3STYu with a scale obtained after holding for 25 hours with the location of the scan points is shown in Figure 2. The chemical composition of the scanned areas is presented in Table 2.



**Figure 2.** The lateral surface of a thin section of a metal of composition 30N8Kh6M3STYu with an oxide layer after a scale test at 900 °C – 25 hours with the location of the scan areas at points.

**Table 2.** The chemical composition of the scanned regions of the metal composition 30N8Kh6M3STYu after test for scale resistance at 900 °C – 25 hours.

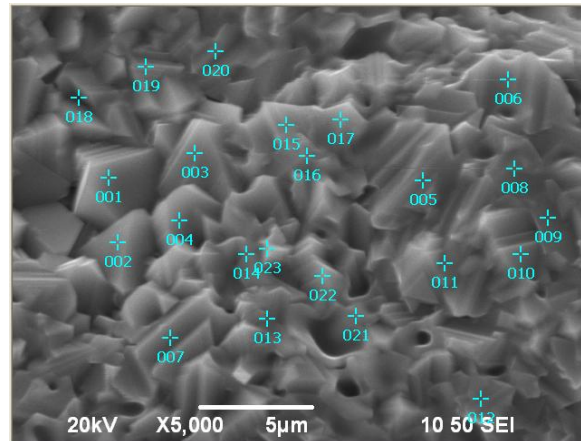
Point No	N	O	Al	Si	Ti	Cr	Fe	Ni	Mo
1	0	0	0.04	1.52	0.21	6.12	83.89	8.25	3.84
2	0	0	0.65	2.69	0.98	5.33	76.28	8.72	6.2
3	1.53	4.07	2.12	4.9	3.4	4.34	62.63	7.2	13.83
4	5.52	9.8	0.24	8.1	3.89	12.48	63.67	0.61	5.7
5	0.41	7.52	0.13	0.33	0.71	3.11	89.93	0.85	0
6	0.63	0.52	0	0.33	0	10.56	95.57	0.14	0.26
7	2.05	1.26	0.12	0.49	0.16	7.8	92.4	0.76	1.95

Figure 2 shows that the scale is layered, with many outgoing cavities of various shapes and sizes. In the outer layer of scale, the amount and dispersion of residues of non-oxidized metal is much less than in the layer adjacent to the metal.

The results of chemical analysis show that the concentration in the metal of the main alloying elements Ni, Mo, Cr, Si, Ti, as they approach the transition layer (points 1, 2), remain at a high level. Oxygen and nitrogen appear in the transition layer (point 3), and the concentrations of all alloying elements reach very high values. As approach the surface of the scale (points 4, 5, 6), the concentrations of Ti, Al, Si, Ni, Mo decrease. Directly at the surface (point 7), a high concentration of Cr and Mo is observed.

The results obtained indicate the formation of a significant chemical microinhomogeneity in the deposited coating during oxidation. As approach the scale, metal depletion of the main alloying elements is observed. A rapid decrease in the concentration of the main alloying elements is associated with their active participation in diffusion processes due to high temperatures [12].

The characteristic structure of the surface part of the scale with the location of the scanning points is shown in Figure 3. The chemical composition of scanned objects is given in Table 3.



**Figure 3.** The surface of the oxide layer of the metal with the composition 30N8Kh6M3STYu after the scale resistance test at 900 °C – 25 hours with the location of the scan areas at points.

**Table 3.** The chemical composition of the scanned regions of the surface of the oxide layer of the metal with the composition 30N8Kh6M3STYu after a scale test at 900 °C – 25 hours.

Point No	N	O	Al	Si	Ti	Cr	Fe	Ni	Mo
1	5.34	19.13	0.51	0.1	0.39	12.21	48.45	12.92	0.95
2	0	19.79	1.76	1.11	1.16	8.78	55.77	11.63	0
3	6.76	12.59	0.73	0.27	0.28	11.18	55.61	12.58	0
4	4.4	15.04	1.45	0.58	1.37	14.55	50	11.99	0.62
5	8.16	13.79	1.14	0.29	0.34	14.33	52.14	9.81	0
6	5.16	14.93	0.75	0.37	0.57	12.78	54.13	11.11	0.2
7	5.14	13.14	1.11	1.75	0.11	11.14	55.92	9.74	1.95
8	9.74	18.44	1.13	0.18	0.26	10.2	51.68	8.37	0
9	5.7	14.45	0.61	0.27	0.28	5.93	64.09	8.67	0
10	5.24	21	1.67	0	0	8.77	51.67	10.42	1.23
11	9.72	14.83	0.61	0.09	0.16	6.78	63.87	2.98	0.96
12	5.64	15.88	0.99	0.3	0.46	8.8	57.67	10.26	0
13	5.64	17.15	1.46	2.2	0.33	5.32	60.85	7.05	0
14	2.86	15.09	0.66	0.59	0.24	6.49	71.31	2.76	0
15	13.04	17.21	1.27	0.04	0.29	10.13	49.02	9	0
16	8.32	16.76	0.86	0.51	0.49	8.76	55.75	8.55	0
17	8.88	20.7	1.21	0	0.56	10.03	49.04	9.34	0.24
18	0.84	10.1	0.44	0	0.95	8.93	62.47	14.55	1.72
19	9.3	19.14	1.37	0.23	0.53	12.21	46.05	11.17	0
20	6.86	12.04	0.66	0.23	1.54	10.72	59.08	7.98	0.89
21	7.2	18	0.63	0	0.38	8.41	63.01	1.22	1.15
22	10.26	21.92	1.3	0.83	0.45	11.62	43.86	9.49	0.27
23	0	21.79	1.29	0.51	0.15	9.75	55.25	10.19	1.07

It can be seen that the surface layer of the scale is a randomly entangled mixture of conglomerates of irregularly shaped particles with sizes up to 5  $\mu\text{m}$ . All particles based on Fe, Cr, and Ni contain oxygen, and most of them also contain nitrogen. A number of particles contain all the main alloying elements (points 1, 4, 6, 7, 11, 20, 22, 23). Another series of particles contains mostly Fe, Cr, Ni, Ti, Al (points 2, 4, 5, 6, 13, 15, 17, 19, 20, 22). In some objects, a high concentration of Mo is observed (points 1, 4, 7, 10, 11, 18, 20, 21, 23).

The results of x-ray diffraction analysis of the metal scale composition 30N8Kh6M3STYu after exposure for 25 hours at a temperature of 900 °C are shown in table 4.

**Table 4.** The phase composition of the metal scale composition 30N8Kh6M3STYu after exposure at a temperature of 900 °C.

No	Phase designation and card number	Int.	Type of lattice	Lattice parameters
1	Fe <sub>2</sub> O <sub>3</sub> (96-154-6384)	920	trigonal (hexagonal axis)	a = 5.0300 Å c = 13.7500 Å
2	Fe <sub>3</sub> O <sub>4</sub> (96-900-2320)	820	cubic	a = 8.3517 Å
3	Cr <sub>2</sub> FeO <sub>4</sub> (96-900-7326)	590	cubic	a = 8.3765 Å
4	Fe (96-900-6602)	420	cubic	a = 3.1590 Å
5	Fe <sub>2</sub> NiO <sub>4</sub> (96-230-0296)	110	cubic	a = 8.35966 Å
6	Fe <sub>3</sub> N 96-231-0870	105	trigonal (hexagonal axis)	a = 4.71600 Å c = 4.39400 Å
7	Ni <sub>1.875</sub> O <sub>2</sub> (96-152-8875)	85	monoclinic	a = 5.1150 Å b = 5.9580 Å c = 5.9540 Å
8	TiO <sub>2</sub> (96-900-8217)	44	tetragonal	a = 125.190 Å c = 3.8040 Å
9	Ni <sub>2</sub> SiO <sub>4</sub> (96-152-9934)	43	cubic	c = 9.6140 Å a = 7.9840 Å
10	MoN <sub>0.506</sub> (96-152-8389)	42	cubic	a = 4.16158 Å
11	FeCO <sub>3</sub> (96-901-5261)	40	trigonal (hexagonal axis))	a = 4.5270 Å c = 13.5700 Å
12	Al <sub>2</sub> O <sub>3</sub> (96-152-8428)	40	hexagonal	a = 3.1120 Å c = 4.9880 Å
13	Mo <sub>2</sub> C (96-153-9796)	40	orthorhombic	a = 4.7350 Å b = 6.0250 Å c = 5.2100 Å
14	Al <sub>2</sub> FeO <sub>4</sub> (96-900-5171)	36	cubic	a = 8.1522 Å
15	Al <sub>2</sub> CO (96-153-7348)	34	hexagonal	a = 3.2000 Å c = 5.1000 Å
16	TiN (96-110-1082)	30	cubic	a = 4.2410 Å
17	Mo <sub>3</sub> O (96-152-8029)	28	cubic	a = 5.5490 Å

The obtained results show that the basis of the metal scale of composition 30N8Kh6M3STYu is hematite Fe<sub>2</sub>O<sub>3</sub>, magnetite Fe<sub>3</sub>O<sub>4</sub> and Cr<sub>2</sub>FeO<sub>4</sub>, as well as Fe<sub>2</sub>NiO<sub>4</sub> and Fe<sub>3</sub>N, and in small quantities Ni<sub>1.875</sub>O<sub>2</sub>, TiO<sub>2</sub>, Ni<sub>2</sub>SiO<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub>, MoN<sub>0.506</sub>.

Thus, the presence of compounds with high protective properties in the scale composition determines the increased scale resistance of the deposited metal. The increase in the mass of scale is 16.5 times less, and its thickness is 11 times less than that of the metal deposited by wire 30Kh2V8F. The results obtained show that the metal deposited by flux-cored wire PP30N8Kh6M3STYu can be used for coating a tool operating at high temperatures.

#### 4. Conclusion

1. The investigated coating of steel 30N8Kh6M3STYu is subject to slight surface oxidation. The average weight gain of the metal scale of such a coating at 900 °C is 0.002 kg/(m<sup>2</sup>·h).

2. The coating made of steel 30N8Kh6M3STYu can be used for applying to the surface of parts operating at high temperatures up to 900 °C.

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